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Life Cycle Assessment Performed on a CCS Model Case in Japan and Evaluation of Improvement Facilitated by Heat Integration

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Abstract

Carbon Dioxide Capture and Storage (CCS) is a technology for reducing the amount of CO_2 to be emitted into the air, by storing the CO_2. However, a CCS project itself emits some CO_2. Therefore, to estimate CCS's net CO_2 reduction effect, it is effective to apply life cycle assessment (LCA) to CCS projects. In this paper, we assumed a number of CCS project models to be feasible in Japan, and estimated the amount of CO_2 emissions to store one ton of CO_2 by applying LCA to the CCS projects. As a result, depending on the model case, 50% or more of the CO_2 amount to be stored was emitted. The study also revealed that approximately 80% of the CO_2 emissions at CCS-applied facilities derived from the energy consumed to re-heat the liquid absorbent that absorbed CO_2. The study also indicated that a substantial amount of CO_2 emissions can be reduced if heat integration is conducted between the production equipment and the CCS equipment for energy utilization, such as bleeding CO_2 from a power station and other production equipment.

Keywords: CCS; Carbon Dioxide Capture and Storage; LCA; life cycle assessment; heat integration

1. Introduction

CO_2 capture and storage technology is a measure to combat global warming. To assess the technology, it is essential to estimate and assess all types of input energy relating to the materials and energy used at and operations of a power station, the source of CO_2 emissions, as well as the total amount of CO_2 emissions in the series of processes ranging from CO_2 separation and capture at the power station, transport of the separated and captured CO_2 from the power station, and to storing CO_2 underground.

The Research Institute of Innovative Technology for the Earth (hereafter "RITE") conducted LCA-applied analyses of CO_2 underground storage in 2001 and 2001[1]. In 2000 and 2006, RITE also formulated a number of model cases at places that emit a large amount of CO_2[2]. With these study results, it is possible to conduct an LCA of CCS processes consisting of specific systems.

This study performed an LCA analysis of respective model cases and compared and identified which processes emit a large amount of CO_2 ranging from CO_2 separation and capture to underground storage. The LCA method-applied CCS performance assessment could be used for public acceptance activities and CCS accountability.

2. Setting up Model Cases

We selected two places (Hokkaido and Niigata) on the Japanese coast as LCA-applied CCS project model cases and set up the following six model cases (System A to F).

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2.1. Hokkaido area

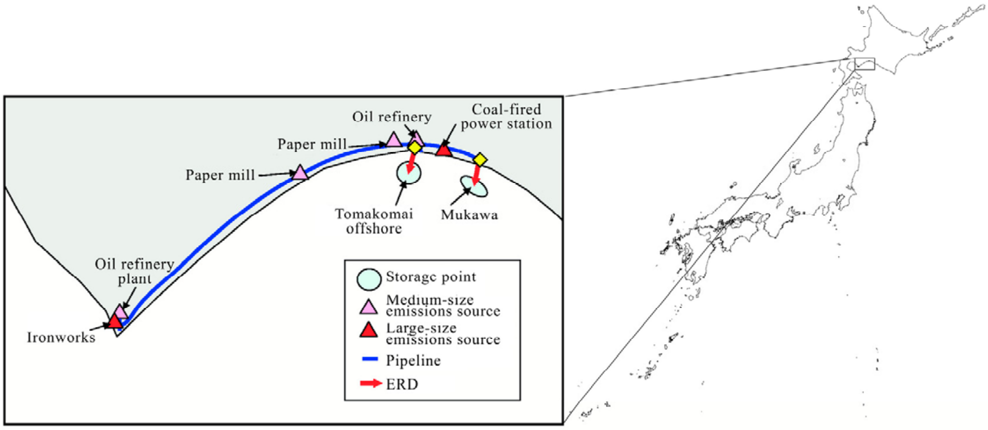
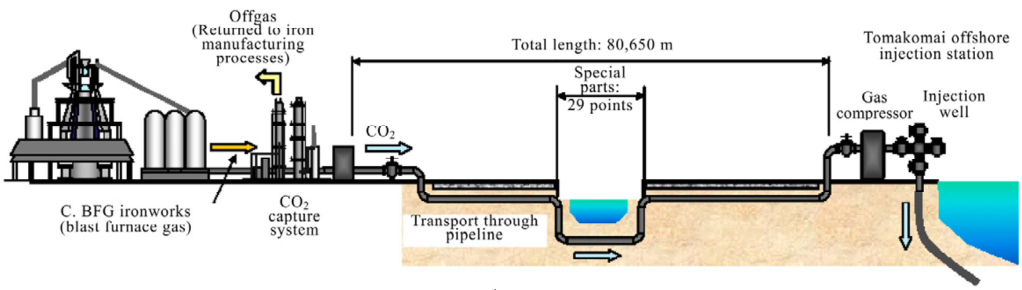
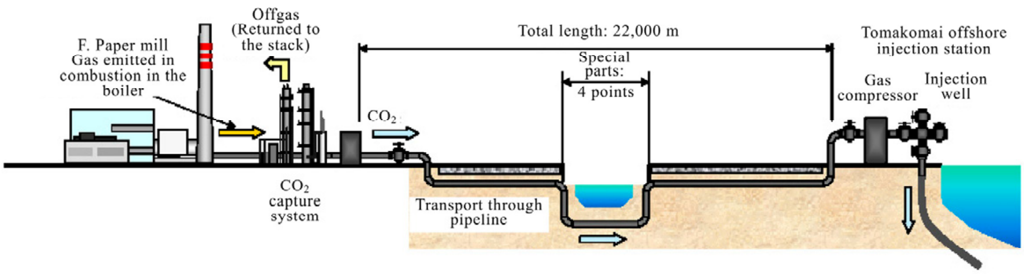


Figure 1 Model Case in Hokkaido Area



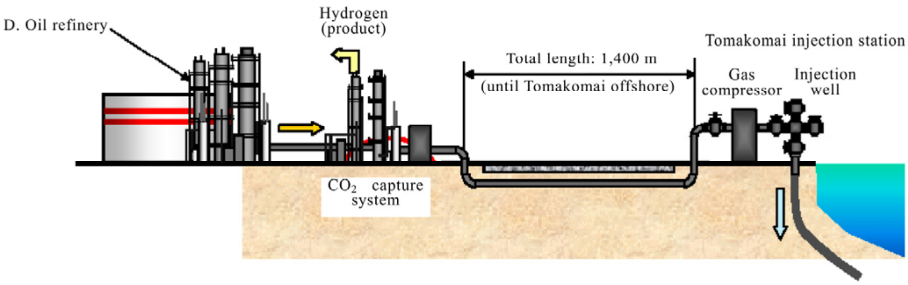
CO_2 generation source	Ironworks	Target gas	BFG (blast furnace gas)
Capturing size	One million tons/year	CO_2 concentration of emissions gas	22%
Transport distance	80.65 km	Separation and capture methods	DEA
Injection point	Tomakomai offshore	Pre-processing	Removal of retarding elements and dust
Injection method	ERD, beneath the seabed		

Figure 2 System A



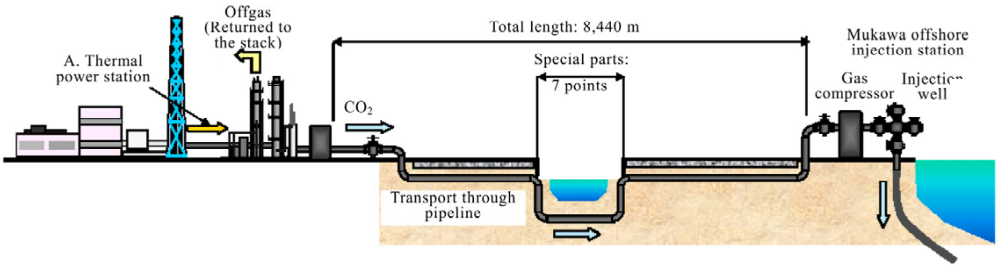
CO_2 generation source	Paper mill	Target gas	Gas emitted from the boiler using black liquor
Capturing size	0.34 million tons/year	CO_2 concentration of emissions gas	13%
Transport distance	22.00 km	Separation and capture methods	MEA
Injection point	Tomakomai offshore	Pre-processing	-
Injection method	ERD, beneath the seabed		

Figure 3 System B



CO_2 generation source	Oil refinery	Target gas	PSA feed gas accompanying the hydrogen generator
Capturing size	0.34 million tons/year	CO_2 concentration of emissions gas	20.90%
Transport distance	1.40 km	Separation and capture methods	aMDEA
Injection point	Tomakomai offshore	Pre-processing	-
Injection method	ERD, beneath the seabed		

Figure 4 System C



CO_2 generation source	Coal-fired power station	Target gas	Post-combustion gas emitted from the desulfurizer outlet
Capturing size	One million tons/year	CO_2 concentration of emissions gas	12.40%
Transport distance	8.44 km	Separation and capture methods	KS-1
Injection point	Mukawa offshore	Pre-processing	-
Injection method	ERD, beneath the seabed		

Figure 5 System D

2.2. Niigata Area

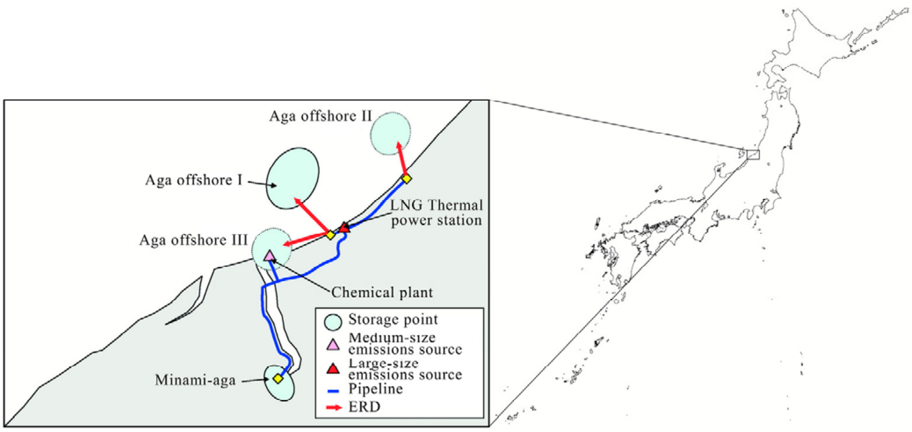
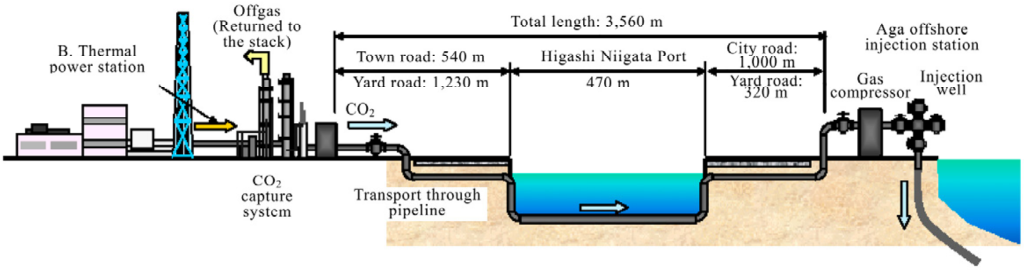
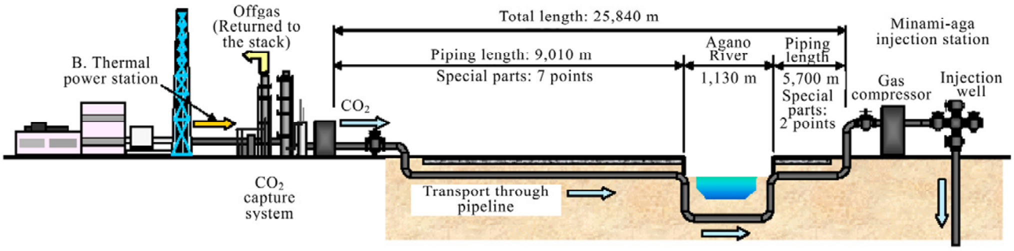


Figure 6 Model Case in Niigata Area



CO_2 generation source	Thermal power station (LNG conventional)	Target gas	Post-combustion gas emissions
Capturing size	One million tons/year	CO_2 concentration of emissions gas	8.40%
Transport distance	80.65km	Separation and capture methods	KS-1
Injection point	Aga offshore	Pre-processing	-
Injection method	ERD, beneath the seabed		

Figure 7 System E



CO_2 generation source	Thermal power station (LNG conventional)	Target gas	Post-combustion gas emissions
Capturing size	One million tons/year	CO_2 concentration of emissions gas	3.80%
Transport distance	80.65 km	Separation and capture methods	KS-1
Injection point	Minami-aga	Pre-processing	-
Injection method	On land		

Figure 8 System F

3. Setting up System Boundaries

The boundaries of an LCA system were defined as from receiving emissions gas from a CO_2 emissions source in the separation and capture plant to injecting CO_2 underground. The LCA targets were also defined as the manufacture of the equipment used in the above processes, separation and capture plant, pipelines, and utilities that operate the injection equipment (steam and electric power as heat sources). Specifically, we targeted CO_2 emitted in the following processes.

1) CO_2 emitted in the manufacturing of the equipment used for the separation and capture plant
2) CO_2 emitted from the use of electric power consumed in the separation and capture plant and CO_2 emitted in coal combustion in the boiler for generating steam
3) CO_2 emitted to produce the liquid absorbent used for CO_2 separation and capture
4) CO_2 emitted in the manufacturing of a pressure rising machine used for transporting captured CO_2
5) CO_2 emitted for the consumption of electric power to operate the pressure rising machine used for transporting the captured CO_2
6) CO_2 emitted in the manufacturing of the injection system
7) CO_2 emitted in the consumption of electric power to operate the injection system

For the equipment and apparatus used for the separation and capture plant, pipelines, and injection stations and others, we estimated the amount of CO_2 emissions during manufacturing of the equipment and apparatus. These amounts were equally distributed to each of the 20 years that we assume as the useful years of operation of the plant.

4. CO_2 Emissions Intensity

4.1. Carbon dioxide emissions intensity for steam used in a chemical absorption method

A heat source for re-heating is necessary in this chemical absorption method because the liquid absorbent that absorbed CO_2 must be re-heated to capture CO_2.

This study assumes, as a basic case, that a new coal-fired boiler installed supplies steam. The specifications are defined as stated below. Based on the specifications, we obtained CO_2 emissions that can generate 1kg steam, which was defined as the CO_2 emissions intensity.

Table 1 Specifications of Coal-Fired Boiler

Item	Quantity	Unit	Remarks
(A) Steam flow generated	260	t/hr Steam	-
(B) Amount of fuel consumed	23	t/hr Coal	-
(C) Amount of energy consumed for coal	26.6	MJ/kg	-
(D) Amount of energy consumed	611,800	MJ	(B)*(C)*1,000
(E) Amount of energy per steam flow	2.35	MJ/kg-steam	(D)/(A)
(F) CO_2 emissions coefficient	0.0906	$kgCO_2/MJ$	Emissions coefficient of steam coal
(G) CO_2 emissions	55,429	$kgCO_2/hr$	(D)*(F)
(H) CO_2 emissions per steam flow	0.21	$kgCO_2$/kg-steam	(G)/(A)

4.2. Intensity for electric power

To the CO_2 intensity of electric power, we applied 0.41kg-CO_2/kWh, which is the CO_2 emissions intensity at the use end announced by the Federation of Electric Power Companies of Japan[3].

4.3. Intensities for facilities, equipment, and apparatus

Based on the documents obtained, we estimated the materials and their quantities to be consumed by the CCS related facilities, equipment and apparatus, and calculated those costs. Then, based on the cost calculation results, we estimated CO_2 emissions at the stage of manufacturing those facilities, apparatuses and equipment by applying the *inter-industry relations method.*

The *inter-industry relations method* uses the *Interindustry Relations Table*, which covers 401 categories covering articles transacted in Japan. The table indicates the CO_2 emissions intensities and energy consumption intensity of each of the 401 categories. Table 2 lists CO_2 emissions intensities of facilities obtained in the inter-industry relations method.

Table 2 Specifications of Coal-Fired Boiler

Code ID	Product name	CO_2 emissions intensity (t-CO_2/million yen)
167	Steel pipe	17.196
194	Boiler	2.601
197	Carrier	2.980
199	Pump and compressor	3.357
203	Chemical apparatus	2.212

5. Lice Cycle Assessment (LCA)

The following table lists results of our life cycle assessment of individual systems in the method mentioned above.

Table 3 CO_2 Emissions Amount by LCA Analysis of Each System

		System					
		A (Iron manufacturing)	B (Paper manufacturing)	C (Oil production)	D (Coal-fired)	E (LNG)	F (GTCC)
Facilities	Separation and capture	276	730	101	351	102	832
	Pressurization	403	436	252	436	89	520
	Pipeline	18,228	4,502	181	1,462	464	5,589
	Injection	235	235	133	235	54	302
Utility	Separation and capture (steam)	501,776	427,333	88,414	286,313	29,548	308,911
	Separation and capture (electric power)	12,228	18,062	1,515	11,660	1,421	32,546
	Transport and injection (electric power)	53,650	52,585	23,301	55,063	4,391	57,859
Total		586,796	503,883	113,897	355,520	36,069	406,559
CO_2 injection		1,000,000	1,000,000	340,000	1,000,000	1,000,000	1,000,000

The following table lists the amount of CO_2 emissions per ton of CO_2 injection calculated based on the results indicated above.

Table 4 Amount of CO_2 Emissions per Ton of CO_2 Injection of Each System

		System					
		A (Iron manufacturing)	B (Paper manufacturing)	C (Oil production)	D (Coal-fired)	E (LNG)	F (GTCC)
Facilities	Separation and capture	0.00	0.00	0.00	0.00	0.00	0.00
	Pressurization	0.00	0.00	0.00	0.00	0.00	0.00
	Pipeline	0.02	0.00	0.00	0.00	0.00	0.01
	Injection	0.00	0.00	0.00	0.00	0.00	0.00
Utility	Separation and capture (steam)	0.50	0.43	0.26	0.29	0.03	0.31
	Separation and capture (electric power)	0.01	0.02	0.00	0.01	0.00	0.03
	Transport and injection (electric power)	0.05	0.05	0.07	0.06	0.00	0.06
Total		0.59	0.50	0.33	0.36	0.04	406,559

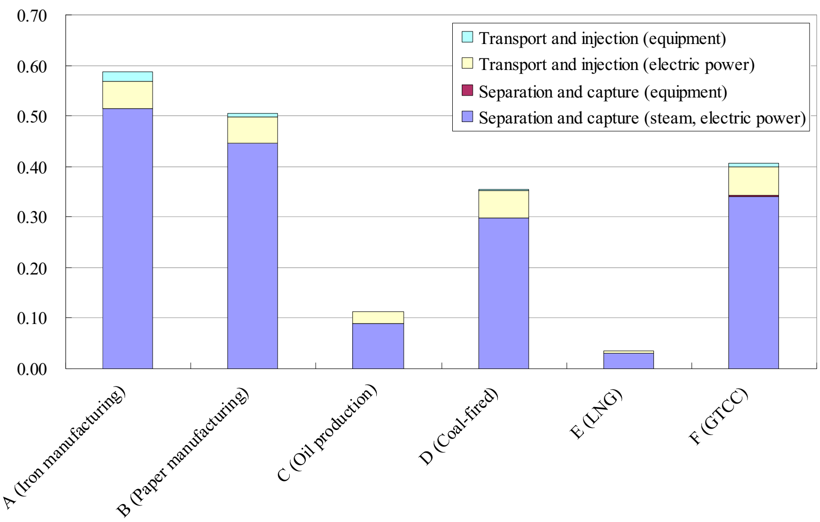


Figure 9 Amount of CO_2 Emissions per Ton of CO_2 Injection of Each System

As a result of our life cycle assessment, we estimated that, to store one ton of CO_2, an ironworks emits 0.59 tons of CO_2; a paper mill emits 0.50 tons of CO_2; an oil refinery emits 0.33 tons of CO_2; a coal-fired power station emits 0.36 tons of CO_2.

Among the processes, separation and capture emits the largest amount of CO_2. We found that the process consumes much energy to retain heat (steam) that is necessary to re-heat the liquid absorbent.

6. Analysis of Heat Integration

To reduce CO_2 emissions following CCS implementation, it is effective to develop a liquid absorbent and processes that consume a smaller amount of energy as well as to make heat integration of generation processes with CO_2 separation and capture processes. The studies up to Section 5 above were conducted on the assumption that heat necessary for CO_2 separation and capture was supplied by a new coal-fired boiler. Actually, utilizing energy generated from production equipment is essential. For this purpose, we conducted an LCA of a heat integration case between production processes and CO_2 separation and capture processes at a coal-fired power station as an example.

In connection with this, we used RITE's existing study results[2] for the degree of lowering productivity when energy at the production equipment is diverted to CO_2 separation and capture (power generation loss for a power station case).

As a result, CO_2 emissions (0.09 ton) that are generated when a coal-fired power station separates and captures one ton of CO_2 decreased by approximately 25% if a new coal-fired boiler that can provide heat necessary for CO_2 separation and capture (0.35 ton) is installed.

Table 5 Effects of Improvement in Heat Integration in CCS Application to a Thermal Power Station

			Coal-fired		LNG conventional		GTCC	
Heat integration			No	Yes	No	Yes	No	Yes
Annual CO_2 capture	a	t-CO_2/y	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Annual operation hours	b	h/y	7,900	7,900	6,300	6,300	6,300	6,300
CO_2 capture per hour	c=a/b	t-CO_2/h	127	127	159	159	159	159
Energy needed to capture one ton of CO_2	d	MJ/t-CO_2	3,000	3,000	3,200	3,200	3,200	3,200
Energy needed for capture for one hour	e=c*d	MJ/h	381,000	381,000	508,800	508,800	508,800	508,800
Power generation loss rate	f	kWh/MJ	**-**	**0.04**	**-**	**0.03**	**-**	**0.09**
Power generation loss	g=e*f	kWh/h	-	15,240	-	15,264	-	45,792
Power generation loss	h =g*3.6	MJ/h	-	54,864	-	54,950	-	164,851
Generation efficiency rate (generator)	i	-	-	0.43	-	0.39	-	0.493
Energy consumption equivalent to the portion of power generation loss	j=h*i	MJ	-	127,600	-	140,900	-	334,400
CO_2 emissions intensity of fuel	k	kg-CO_2/MJ	-	0.0906	-	0.0494	-	0.0494
Annual CO_2 emission	l	t-CO_2/y	355,520	-	355,957	-	406,559	-
CO_2 emissions per hour	m	t-CO_2/h	45.0	11.6	56.5	7.0	64.5	16.5
CO_2 emissions per ton CO_2 capture	n =m/c	t-CO_2/t-CO_2	**0.35**	**0.09**	**0.36**	**0.04**	**0.41**	**0.10**

According to the results indicated in Section 5, Life Cycle Inventory Analysis, the rate of CO_2 amount emitted in the separation and capture processes (heat supply) to the entire processes at the CCS-applied coal-fired power station, ironworks, paper mill, and oil refinery account for 84%, 86%, 85%, and 78%, respectively.

Consequently, it can be estimated that a CCS-applied plant other than a coal-fired power station can cut a substantial amount of CO_2 emissions if heat generated in the production processes is utilized for CO_2 separation and capture.

7. Conclusion

In this paper, we considered an ironworks, paper mill, oil refinery, coal-fired power station, LNG conventional thermal power station, and LNG combined cycle thermal power station as major sources of CO_2 emissions and from these facilities, we estimated the LCA-applied amount of CO_2 emissions as model cases to separate, capture, and store CO_2 underground. The results are as follows:

* The new CO_2 amount emitted to store one ton of CO_2 ranged from 0.3 to 0.7 t-CO_2/t-CO_2. Depending on the model case, 50% or more of the CO_2 storage was emitted.
* Approximately 80% of the CO_2 emissions stemmed from coal burned to produce steam that was used for re-heating the liquid absorbent that absorbed CO_2.
* For a method of heat utilization at thermal power stations, a portion of steam for power generation can be used for CO_2 separation and capture. Power generation loss rates when steam for power generation is diverted for another purpose are estimated at up to approximately 0.04 kWh/MJ at coal-fired power stations in future, up to approximately 0.03 kWh/MJ at LNG conventional thermal power stations, and up to approximately 0.09 kWh/MJ at LNG combined cycle thermal power stations.
* If a portion of steam for power generation is bled for CO_2 separation and capture based on the power generation loss rates mentioned above, the CO_2 amount to be emitted for one ton of CO_2 separation and capture is estimated at 0.09 (t-CO_2/t-CO_2) at a coal-fired power station, 0.04 t-CO_2/t-CO_2 at an LNG conventional thermal power station, and 0.10 t-CO_2/t-CO_2 at an LNG combined cycle thermal power station. Consequently, it is estimated that these power stations can cut a considerable amount of CO_2 emission, compared with the case in which a coal-fired utility boiler is newly installed to supply steam.

Acknowledgement

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Reference Documents

[1] "Report on Results of Research and Development of Underground Storage Technology for Carbon Dioxide" (RITE, 2000, 2001)
[2] "Report on Results of Research and Development of Underground Storage Technology for Carbon Dioxide" (RITE, 2005, 2006)
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